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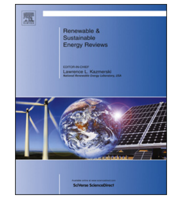

Protection of the environment by using innovative greening technologies in land transport

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ABSTRACT

The continuous growth of population results in more consumption of energy. Moreover, land transport consumes about 35% of the total liquid fuel in most countries. The resulting pollutants cause a tremendous death toll. Hence, it is imperative to enhance the fuel efficiency in transport and protect our environment to make vehicles progressively greener. The engine is an important component for meeting this goal.

The spark ignition engine, by far, is the largest source of motive power in the world. Therefore, continuous endeavors to improve its performance are needed to save fuel, reduce cost and protect the environment.

In this article, nine research investigations carried out by the author and associates during the last few years are briefly reviewed. These researches cover major green tools and technologies which contribute directly in the advancement of land transport especially fuel saving, power boosting and emissions reduction.

This work comprises fundamental studies in modeling and simulation with spark ignition engines S.I.E. and compression ignition engine CIE; impact of alternative fuels with S.I.E.; combustion chamber design; heat transfer in ICE; gaseous pollutants and the environment; and the design of an innovative engine control. Moreover, fuel cells, electric vehicles and biofuels for sustainable future of transport are briefly discussed.

Engineering analysis covered alternative fuels, combustion chamber design, heat transfer, pollutant formation and neuro-fuzzy control.

Contents

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1. Introduction

Reserves of crude oil are continuously decreasing in parallel with growing population and increasing energy demand. Hence, it becomes necessary to enhance energy efficiency in different aspects especially transport, to make vehicles progressively greener. Thereby, the engine is expected to play a major role towards this goal.

Internal combustion engines of all types are, by far, the largest source of motive power in the world. Their many advantages have brought them to this position in spite of their shortcomings. Among the advantages which must be listed are high efficiency, low cost, low weight, long life, versatility and simplicity [1]. The relative importance of the advantages varies with engine type, power output, fuel consumption and application [2]. The trend toward high-performance automobiles made interest in these engines unsurpassed [3].

In the United States, the passenger car sector represents 80% of the total vehicles and uses 70% of the highway fuel. The spark-ignition engine dominates the light-duty vehicle market due to its low initial cost, good performance and good fuel economy [4].

Major changes in engine technology have emerged due to the need to reduce vehicle emissions, reduce fuel consumption, increase the engine specific power and improve vehicle drivability. For the spark-ignition engines, these improvements have come from areas such as development of more sophisticated engine designs with electronic engine control, and the development of the catalytic converter [5]. An energy balance through the engine cycle identifies where the potentially useful work is lost through irreversibilities such as friction, heat transfer and the exhaust-gas flow [6].

2. Systems analysis

This analysis focuses on several tools and technologies utilized by the author and associates in nine previous international publications. These technologies may boost power, reduce fuel consumption and save the environment from tons of gaseous pollutants emanating from land transport. They are briefly mentioned in the following sections.

2.1. Modeling and simulation [7,8]

Modeling is important because it saves time, effort and cost needed for engine development and prediction of performance. This could cover losses due to imperfect construction of the real engine including progressive combustion, valve timing, heat transfer and engine friction. Hence, it becomes possible to convert the output of the fuel–air cycle into net real performance. Simulation of engine performance is usually carried out by varying engine speed, compression ratio r_c, and the spark advance over wide range. Then it becomes possible to compare the results of modeling with those from experiment to explore the accuracy of modeling.

Impact of alternative fuels is important because it affects engine performance and the resulting pollutants. The increased use of automobiles and the rapid rate of industrial development in the world made petroleum supplies unable to keep up with the demands. Petroleum fuels usually pollute the environment with their combustion products. Control devices are used to reduce pollution but they also reduce vehicle mileage [9]. Alternative fuels cover wide variety, mainly alcoholic fuels and gaseous fuel produced from renewable resources, and produce less exhaust pollutants. Gaseous fuels offer cleaner combustion due to their better fuel–air mixture preparation and higher H/C ratios than in the conventional liquid fuels [10].

2.2. Combustion chamber design

The internal combustion engine (ICE) has been continuously developed by carrying out research in different aspects. When gasoline engines are tested using different speeds, combustion appears to be the major contributor to the system inefficiency and all performance parameters were affected by engine speed [11].

The compact chamber spark-ignition engine is one of the methods used to improve the performance of the spark-ignition engines. In this design, the chamber is a bowl-in-piston or in the cylinder head itself. This design will cause swirling of air–fuel mixture, which means better mixing of air–fuel mixture, so the specific fuel consumption will decrease due to leaner mixture and reduction in pumping work. The brake power and efficiency will increase [12,13]. These improvements in performance parameters make it worth using the compact S.I. engine instead of the conventional one.

In the direct-injection stratified (DISC) engine fuel is injected into the engine cylinder just before top–center (like diesel); a spark discharge is then used to initiate the combustion process. At high load, the inlet pressure is boosted by a compressor to above atmospheric pressure. The compressor is geared directly to the engine drive shaft. The exhaust pressure is 1 atm. This DISC engine is suggested to replace an equal displacement conventional naturally aspirated spark-ignition (SI) engine, which has a compression ratio of 8 [14,15].

2.3. Alternative fuels

Harmful effects on environment such as global warming and climate change may result from the gases emanating from fossil fuel combustion. Most countries use fossil fuels exclusively. Reduction of formation and harmful effects of these gaseous pollutants is discussed, with some concentration on energy efficiency and fuel cells in the transportation sector, which has special importance for the developing countries [16]. One-third of the oil used in many countries is used for transportation, namely with passenger cars and light trucks.

2.4. Heat transfer

Temperatures within the combustion chamber of an internal combustion engine reach values in the order of 2700 K [17]. These conditions lead to heat fluxes to the chamber walls as high as 10 MW/m^2 during the combustion period [18]. Hence, to avoid high thermal stresses leading to fatigue cracking, metal temperatures must be less than 400 °C for cast iron and 300 °C for aluminum alloys. The gas side surface temperature of the cylinder wall must be lower than 180 °C to prevent deterioration of the lubricating oil film [19]. Spark plug and exhaust valves must be cool to avoid knock and pre-ignition problems. Thus, removing heat is highly critical to avoid engine failures and considerable influence on operational performance and durability [20].

The calculation of heat transfer is difficult even under steady state conditions. Under the rapidly changing conditions, within engine cylinders, functions for the gas-side heat transfer can only be defined empirically [19]. The problem gets more complicated due to different shapes of combustion chambers, timing and valve lift as they affect flow velocities and directions, change in chemical composition and temperature as a result of combustion, and the heat transfer by gaseous and soot-emitted radiation in addition to convection [20]. Thus, it is not surprising that there are no certain formulae by way of which heat transfer rates in reciprocating engines can be predicted, and that cooling systems of IC engines have always been designed on the basis of experience.

2.5. Vehicle design: engine performance

The overall fuel efficiency of the vehicle has increased considerably over the years due to improvements primarily in aerodynamics, materials, and electronic controls. Saving fuel is not limited to good driving habits. It also involves purchasing the right car, using it responsibly, and maintaining it properly. Driving only when necessary is the best way to save fuel, money, and the environment too.

The most fuel-efficient cars are aerodynamically designed compact cars with a small engine, manual transmission, low frontal area and bare essentials. Front wheel drive offers better traction (because of the engine weight on top of the front wheels), reduced vehicle weight and thus better fuel economy. Radial tires usually reduce the fuel consumption by 5–10% by reducing the rolling resistance [21].

2.6. Engine control

In modern spark ignition engines, the amount of fuel injected is controlled by conventional PID controller that controls the pulse width (PW) applied to the fuel injector. The control map in the conventional PID is represented by three-dimensional nonlinear relationship between the injection time IT (controller output) and the controller inputs: engine speed (N) and manifold absolute pressure (MAP) [22]. However, due to the non-linear nature of this control with the spark ignition engine and the ageing effects of its parts, this controller does not provide good accuracy at each operating point of the engine. Thus, a more accurate digital control system would give better results in terms of performance and pollution [23] e.g. neuro-fuzzy control.

3. Discussion of some relevant research studies

This work is not intended to review the vast literature on research, development and projects related to land transport. It focuses on summarizing nine research investigations carried out by the author and associates, during the last few years.

3.1. Modeling and simulation

Modeling is important because it saves time, effort and cost needed for engine development and prediction of performance.

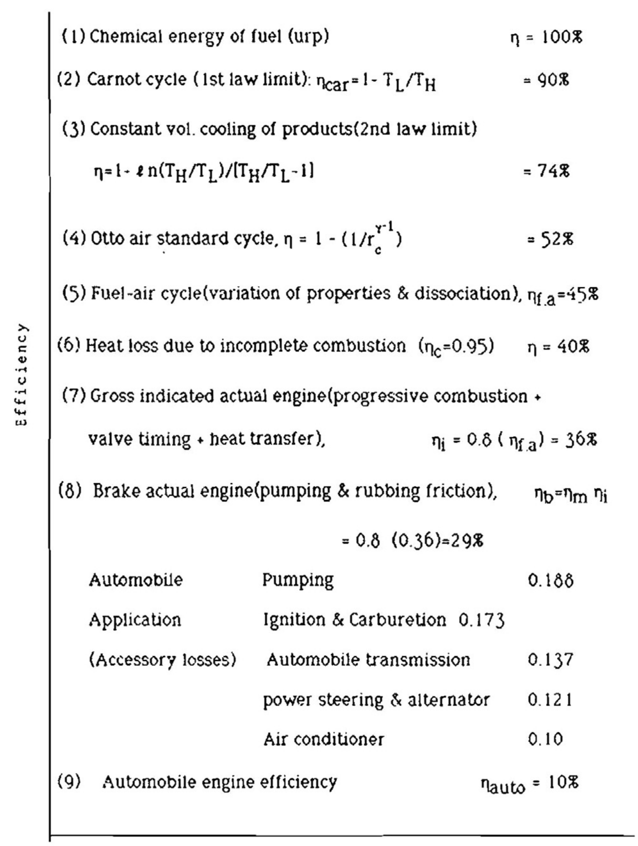

Fig. 1. Schematic diagram showing the effect of different losses, in the automotive spark ignition engine, on efficiency.

Table 1
Properties of fuels.

Property	Gasoline	Diesel
Formula per carbon atom	$CH_{2.045}$	$CH_{1.75}$
Relative molecular mass	100	220
Carbon/hydrogen mass ratio	5.87	6.857
Carbon (wt%)	85.444	87.3
Hydrogen (wt%)	14.556	12.7
Vapor pressure (kg/cm^2)	0.7	
Density (kg/L)	0.733	0.850
Net heat of combustion (kJ/kg)	43705.5	42517
Stoichiometric A/F mass ratio	14.846	14.53
Formula	$C_{7.12}H_{14.56}$	$C_{16}H_{28}$

3.1.1. Modeling and simulation of spark ignition engines

Fig. 1 shows a schematic diagram which explains why all the fuel energy was not converted to work. The magnitude of some losses varies with load or speed [24]. Some of the losses would be different in magnitude, for example, a multi-cylinder or a turbo-charged engine; where friction would be lower and fuel economy better [25]. There is some arbitrariness in assigning losses, so the magnitudes shown in Fig. 1 should not be taken very precisely. However, it suggests where the losses are and where effort should be exerted to improve the performance of the engine.

Except the brake work, all other availability terms represent losses or undesirable transfers from the system; hence decreasing terms constitutes an improvement. These undesirable available energy transfer and destruction terms fall into five categories: (1) combustion (2) heat transfer, (3) exhaust to ambient, (4) fluid flow and (5) mechanical friction [26].

The combustion and exhaust losses can be combined with the ideal cycle models to convert the loss inavailability due to heat transfer, fluid flow, and mechanical friction as real engine effects [27–29].

Incomplete combustion causes thermal energy release to be less than the chemical energy of the fuel *hence*, with combustion efficiency η_c=0.95, η=0.4 as shown by level 6. This incomplete combustion results in the formation of CO and UHC as pollutants. Imperfect construction of the real engine, including finite combustion rates, *valve* timing and throttling, heat transfer to cylinder walls, and incomplete combustion, produce some reduction from the ideal engine, represented by the fuel–air cycles about 20% [30] leaving the real engine with a gross indicated efficiency η_i=0.36.

Only about 10% of the auto's energy input reaches the drive axle as useful work. The accessory losses include pumping, ignition and carburetion, automatic transmission, power steering and alternator, and air conditioner [31], leaving final efficiency about 10% as shown by level 9.

Table 2 shows the variation in efficiency along with power and SFC due to these modifications at the design point. The trends for power, SFC and efficiency are as expected. Plots for variation of power and SFC with other variables such as compression ratio CR and spark advance SA have been canceled in favor of brevity.

Table 2
Variation in power, SFC and efficiency due to modifications on the ideal engine at design point ($Q_{in,i}$=32.833 kW; SFC_i=199.74 g/kWh).

	Power (kW)	SFC (g/kWh)	η (%)
Engine with			
Ideal cycle	13.54	199.74	41.24
p.c	12.24	211.08	37.28
v.t	11.3	239.88	34.42
h.t	10.52	257.02	32.04
Friction	9.1	297.0	27.72

Table 3
Variation in power, SFC and efficiency due to modifications on the ideal engine at design point ($Q_{in,I}$=2.521 kW; SFC=152.92 g/kWh).

	Power (kW)	SFC (g/kWh)	η (%)
Engine with			
Ideal cycle	12.47	152.92	55.37
p.c	9.13	208.81	40.54
v.t	8.06	236.52	35.79
h.t	7.79	244.82	34.59
Friction	5.35	330	23.76

3.1.2. Modeling and simulation of compression ignition engines

This work is a continuation for the previous one on modeling of spark-ignition engine [7]. Hence, the detailed backgrounds are almost similar. Further consideration of losses could be found in [31–35]. As far as the experimental facility is concerned, the same test facility and procedure, previously mentioned, have been used with the same engine converted to a compression ignition engine after some modifications such as using fuel injection system instead of the carburetor. The fuel used is light diesel which has the properties shown in Table 1.

Table 3 shows the variation inefficiency along with power and SFC due to these modifications at the design point.

3.2. Alternative fuels

3.2.1. Performance of automotive reciprocating engines with different fuels [36]

The shortage of fuel reserves and the increasing interest in using cheaper fuels brought about the gradual broadening of fuel specifications. This involves reduction in hydrogen content, vapor pressure and increase in average boiling point.

The candidate alternative fuel for gasoline in automotive applications is the diesel fuel. This is due to the merits of the diesel engine as an automotive power with greatly enhanced fuel economy. However, other fuels have been considered as alternative automotive fuels such as isooctane, methanol [37], and ethanol [38]. Anyhow, the means of producing these fuels are considered less conventional than those of petroleum fuels.

Researchers usually compare gasoline and diesel engines at equal swept volume. Others compare engines whose maximum

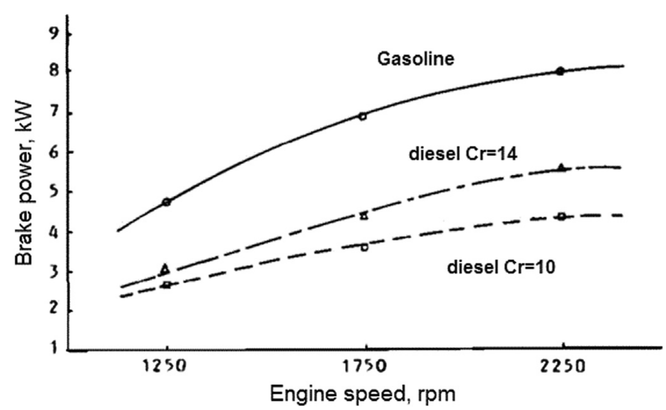

Fig. 2. Comparison of brake power with gasoline and diesel over a range of running speeds.

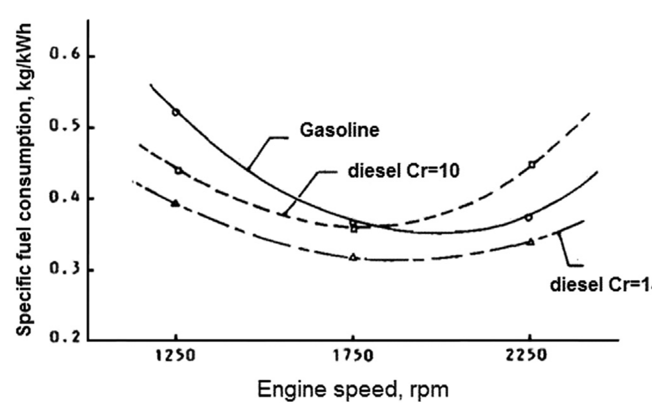

Fig. 3. Comparison of specific fuel consumption with gasoline and diesel over a range of running speeds.

power is the same, implying for the diesel engine a larger swept volume and therefore larger and heavier engines and smaller brake mean effective pressure [39].

In this work the performance with gasoline and diesel oil has been carried out with the same swept volume, running speeds and even the same compression ratio. Hence the fuel effect has been distinguishably characterized. The tests with gasoline were carried out at compression ratio 10 and over a range of running speeds 1250–2250 rpm.

As far as the tests with diesel oil, the compression ratios were 13, 14 and 15 the results of which were extrapolated to a compression ratio 10 for the same range of running speeds to facilitate the comparison with the gasoline tests leaving the fuel type as the main parameter.

Fig. 2 shows a comparison of brake power with gasoline and diesel oil over a range of running speeds (1250–2250 rpm).

However this will adversely affect the fuel economy as shown in Fig. 3, where the diesel engine gives better specific fuel consumption than the gasoline engine up to 1750 rpm at compression ratio of 10 and over much wider range of speeds at a compression ratio of 14.

3.2.2. *Alternative fuels for spark–ignition engines [40,41]*

In this work three types of fuels are investigated: alcoholic fuels, gaseous fuels and liquid fuels. Table 4 shows their operating particulars, whereas Table 5 shows the design values.

Control devices were used to reduce pollution, but resulted in about 15% reduction in the vehicle mileage [42]. It is, therefore, worthwhile to look into the suitability of using “clean” burning fuels for use in spark ignition engines (S.I.E.) [43,44].

Fuel handling and delivery to the injection point into the engine is related to fuel properties such as viscosity, cloud point, pour point and vapor pressure.

Initiation of combustion is related to spontaneous ignition temperature T_{sp}, vapor pressure, viscosity, volatility, stoichiometric F/A ratio $(F/A)_s$ and flame speed [45] combustion stability is affected by laminar flame speed S_L, flammability limits, viscosity and T_{sp}.

3.2.2.1. Alternative fuels–engine relationship. A computer program initiated by Campell using C_8H_{18} as fuel [46] was utilized and then further modified to compare the performance of spark ignition engine S.I.E., using gasoline taking into consideration the four following modifications on the fuel–air cycle, namely progressive combustion, valve timing, heat transfer and friction [46]. The operating variables namely r_c, SA and rpm were varied as shown in Table 6 with gasoline, and the corresponding experimental results were obtained. The experimental device was a single cylinder variable compression engine.

This success in using the modified model to predict performance with gasoline encouraged its use with other fuels which are

Table 7
Parameters of compact chamber and conventional engines.

	Compact chamber 1.5 L	Conventional 1.5 L
Compression ratio	14:01	9:01
Air/fuel ratio at WOT	17:01	13:01
Air/fuel ratio at cruise conditions	22:01	16:01

Table 4
Operating particulars of the different fuels.

Property	RON	$\phi_{mis\ fire}$	ϕ_{pl}	ϕ_{fl}	$(O_2/F)s$	HV (MJ/kg)	MM (kg/kmol)	r_c
$C_{7.12}H_{14.56}$	95	0.8	0.9	1.2	10.76	43.7	100	8
CH_3OH	105		0.8	1.3	1.5	20	32	12
$C_{1.1}H_{4.2}$	120	0.5	0.6	1.1	2.15	50	17.4	14
$C_{0.58}H_{0.84}O_{0.58}$	–	0.5	–	1.1	0.5	15.5	17	14
2 % H_2+gasoline	98	0.5	0.7	1.3	11.04	49.68	100	8

Table 5
Design points for the fuels.

Fuel	Iso-octane	Gasoline	Methanol	CNG	Syn. fuel	H_2+gasol.
CR	9	9	12	14	14	9
rpm	2500	2500	2500	2500	2500	2500
ϕ	1.2	1.2	1.3	1.1	1.1	1.3
SA	20	20	20	15	20	20

Table 6
Operating variables and results of different fuels at design point.

Fuel	C_8H_{18}	$C_{7.12}H_{14.56}$	CH_3OH	$C_{1.1}H_{4.2}$	$C_{0.58}H_{0.84}$	Gasol.+H_2
Φ	1.2	1.2	1.3	1.1	1.1	1.3
N (rpm)	2500	2500	2500	2500	2500	2500
SA (°)	20	20	20	15	20	20
Brake power (kW)	12.31	12.16	15.42	11.08	11.1	12.5
Torque (N m)	48.4	47.75	60.85	42.32	42.4	51.22
BSFC (g/kW h)	302.59	311.08	575.39	254.03	811.96	335.78
η (%)	26.61	26.48	26.88	30.33	28.6	23.7

considered as candidate alternative fuels for the S.I.E., such as methanol CH_3OH, natural gas NG, synthetic gas from coal, and mixture of gasoline and hydrogen. The operating particulars of these fuels along with gasoline are shown in Table 5. Thus, further modifications in the modified computer program are carried out to take these particulars into consideration.

In addition to the basic three operating variables namely N, Φ and SA which were used with gasoline, the compression ratio r_c is now added to represent the effect of fuel on knock requirements of the engine. Table 6 shows the values of these variables at the design point with six fuels. Table 7 gives the overall picture of operation and performance at the design point for the different fuels.

Hence, it becomes possible to draw Fig. 4 which shows a nice comparison of the different fuels on the P–V diagram at their design points. However, they are not very different at BDC due to using the same engine for all the fuels.

Therefore, Fig. 5 is drawn to show the P–r_c diagrams for the different fuels which have different design compression ratio depending on fuel properties. Now the differences are more obvious at BDC.

3.2.3. *Comparison of performance of compact chamber spark ignition engine with conventional S.I. engine [47]*

This paper deals with the compact chamber engine in which a bowl-like space in the piston or head of the cylinder is added in order to cause swirling of the air–fuel mixture. This causes a change in performance from the conventional spark ignition engine.

In this work, the operating variables considered are the engine speed, equivalence ratio, inlet pressure and temperature and exhaust pressure.

Hybrid electric vehicles powered with alternative fuels proved the importance of the fuel-flexible ICE. It can be used with emerging hydrogen in the market [48–50].

Exhaust gas recirculation EGR was tried as a means of improving energy efficiency in low-temperature combustion, where NO_x and soot decrease but thermal efficiency also decreases. The impact of heat-release phasing, duration, shaping and splitting on thermal efficiency has been analyzed [51–53]. The influence of advance injection timing on performance and emissions of CI engine fueled with ethanol-blended diesel fuel showed that NO_x emissions increased but smoke, HC and CO emissions decreased for all test fuels [54,55].

Swirl results in higher turbulence inside the chamber during combustion, thus increasing the rate of flame development and propagation [3]. This will lead to using more lean mixture, and increasing turbulence in unburned mixture at the time of combustion which increases the burning rate.

A fast combustion process reduces cyclic combustion variability for the following reasons. Faster burn results in, the optimum spark timing will be closer to top-dead center; mixture temperature and pressure at the time of spark are higher, so the laminar flame speed at the start of combustion is greater. This, combined with turbulence of most fast-burn concepts, results in faster flame development.

However, in this work these things were taken in consideration. The fuel used is gasoline ($C_{7.931}H_{14.831}$) with molecular weight equals to 110, relative density=0.72–0.78, heat of vaporization=305 kJ/kg, HHV=47.3 MJ/kg, and LHV=44 MJ/kg. The pressure drop in the intake manifold, which is followed by the pressure drop through the valves, is taken into consideration.

Accurate curve fitting equations were carried out for the gross mean effective pressure and for indicated fuel conversion efficiency.

The data of the two engines are shown in Table 7.

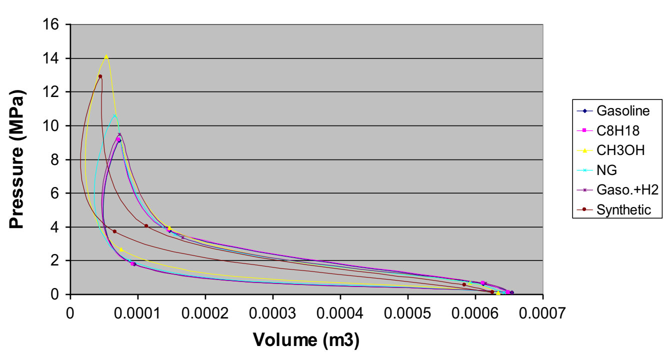

Fig. 4. Pressure volume diagram for different fuels at their design point.

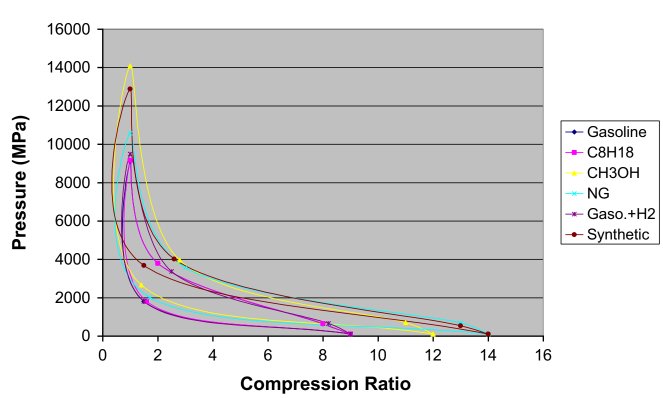

Fig. 5. Pressure versus compression ratio for different fuels.

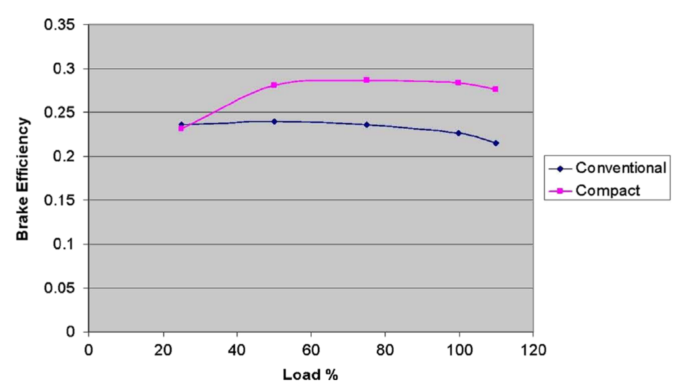

Fig. 6. Comparison of brake efficiency for compact and conventional chamber with different loads engines at $T_{a,o}=30^{\circ}$.

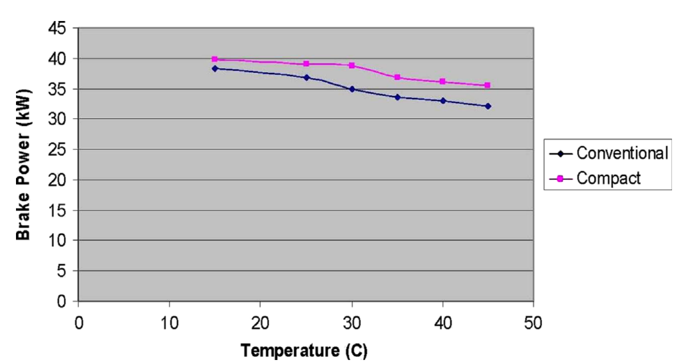

Fig. 7. Comparison of brake efficiency for compact and conventional chamber with different ambient temperatures.

The stoichiometric air–fuel ratio for gasoline is 14.6.

The equivalence ratio (Φ) is the ratio of the actual fuel–air ratio $(F/A)_{act}$ to the stoichiometric fuel–air ratio $(F/A)_s$. The density of the air (ρ_a) can be calculated using ideal gas law at different air temperatures (T_a) and air pressures (p_a). Generally, several performance parameters were improved when the compact chamber engine is used.

Fig. 6 shows the effect of load on brake efficiency for the compact chamber and conventional engines at ambient temperature $T_{a,o}=30\ ^{\circ}C$. It is clearly shown that the compact chamber engine excels the conventional engine in brake efficiency more than 30% at full load.

For the compact chamber the brake efficiency increases with increase in the load, with maximum efficiency in the range of 75% of full load and then it starts to decrease with increase in the load [56–62].

Fig. 7 shows the effect of ambient temperature on brake power for conventional and compact chamber engine at full load (constant load). It is clearly shown that the relation between the brake power and the ambient temperature is inversely proportional. The drop in the air density is small so this will lead to small decrement in the brake power [62–65].

3.2.4. Comparison of performance of a direct-injection stratified-charge (DISC) engine with a spark ignition engine using a simplified model [66]

The direct-injection stratified-charge (DISC) engine is a hybrid between spark-ignition and compression-ignition engines; it combines many of the best features of both with some unique advantages of its own. This includes multi-fuel capability, high thermal efficiency, low NO_x production, and low particulate emissions.

This work shows how simple semi-global models can predict the performance of the S.I. and DISC engines with reasonable accuracy, without going to details of modeling for internal processes such as swirl, mixing and detailed combustion kinetics.

The exhaust pressure is 1 atm. This DISC engine is suggested to replace an equal displacement conventional naturally aspirated spark-ignition (S.I.) engine, which has a compression ratio of 8 [67–69].

The principle behind stratified charge engines is to have a readily ignitable mixture in the vicinity of the spark plug, and a weaker (possibly non-ignitable) mixture in the remainder of the combustion chamber. The purpose of this arrangement is to control the power output of the engine by varying only the fuel supply without throttling the air, thereby eliminating the throttling pressure drop losses. The stratification of the charge can be obtained by division of the combustion chamber to produce a pre-chamber that contains the spark plug [70].

Typically fuel would also be injected into the pre-chamber, so that charge stratification is controlled by the timing and rate of fuel injection. The fuel supply is controlled in the same manner as compression ignition engines, yet the ignition timing of the spark controls the start of the combustion [71].

Another means of preparing a stratified charge was to provide an extra valve to the pre-chamber, which controls a separate air–fuel mixture. The Honda-company was the company to produce the first stratified charge engine in regular production [72–75].

For stratified charge operation, the fuel is injected when the cylinder pressure is in the range 3–10 bar, and these pressures make the spray less divergent than with homogenous operation, which has injection when the gas pressure is about 1 bar [76].

The greater spray divergence helps to form a homogenous charge. Furthermore, when injection occurs during the induction process there are two beneficial effects associated with the evaporative cooling from the fuel. Firstly, the volumetric efficiency is increased by 5%, to make it comparable to a port injected engine, and secondly, the gas temperature at the end of compression is reduced by about 30 K.This enables knock-free operation with a 12:1 compression ratio [77].

Fig. 8 shows the variation of brake thermal efficiency of the two engines with load.

The DISC engine is more efficient (40–60%) than the conventional spark-ignition engine at high and light loads, because the DISC engine has high compression ratio, no throttling, and the fuel is injected just before the top center.

3.3. Heat transfer

3.3.1. Parametric study of heat transfer in internal combustion engines [78]

Heat transfer in internal combustion engines is very important, as far as it affects integrity of engine parts, engine performance,

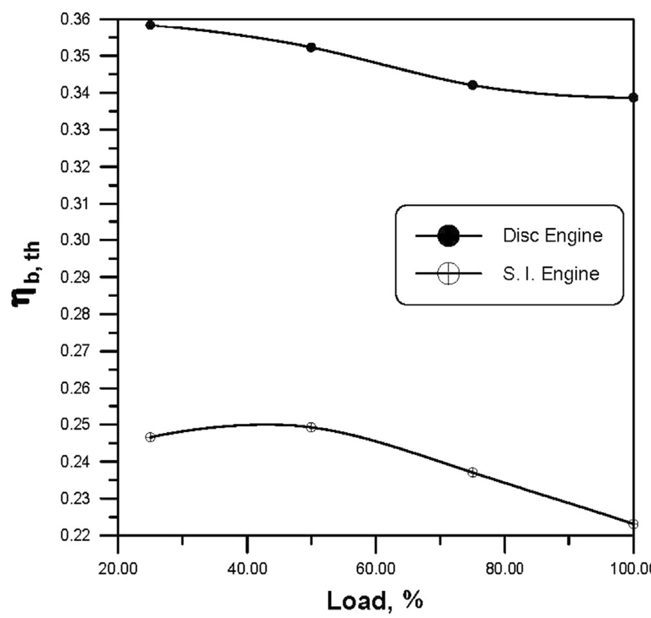

Fig. 8. Relative contribution of design and operating variables in the higher brake thermal efficiency of the DISC engine.

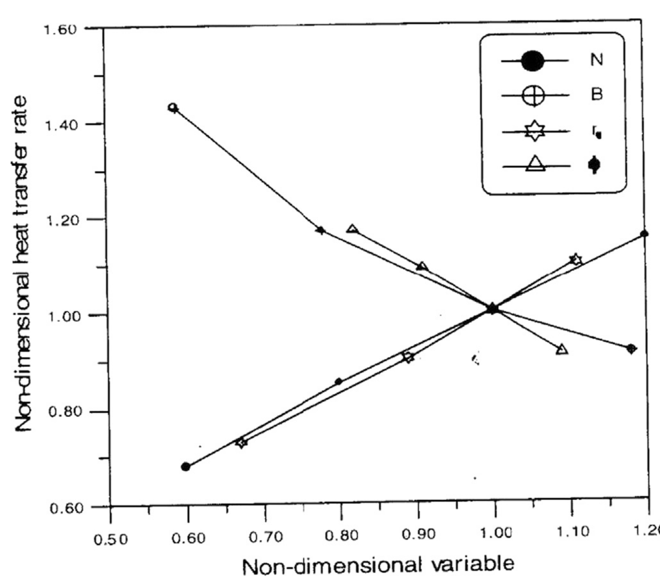

Fig. 9. Effect of non-dimensional variables on normalized heat transfer rate.

emissions, turbocharger design, and ancillary cooling equipment. In this study engine heat transfer was considered to be affected by design and operating variables namely engine speed N, compression ratio r_c, cylinder bore B, and equivalence ratio ϕ. Each was varied over wide range from the design value. Performance parameters namely heat transfer rate Q and heat transfer coefficient were calculated using a specially designed computer program. Results show that increasing N and r_c enhances Q and h_c, whereas B and ϕ have an opposite effect [79,80].

Many investigators have been concluding theoretical and experimental research [79,80] to elucidate the heat transfer characteristics of experimental engines. Recently, theoretical modeling [81–83] has become an important tool for understanding the combustion process and for designing an efficient combustion chamber due the development of high speed electronic computers.

The aim of this work was to study the effect of design and operating variables: engine speed N, compression ratio r_c, cylinder bore B, and equivalence ratio ϕ on performance parameters: heat transfer rate Q and heat transfer coefficient he based on p–θ data at wide-open throttle of a 5.75 L-displacement volume and eight-cylinder spark ignition engine.

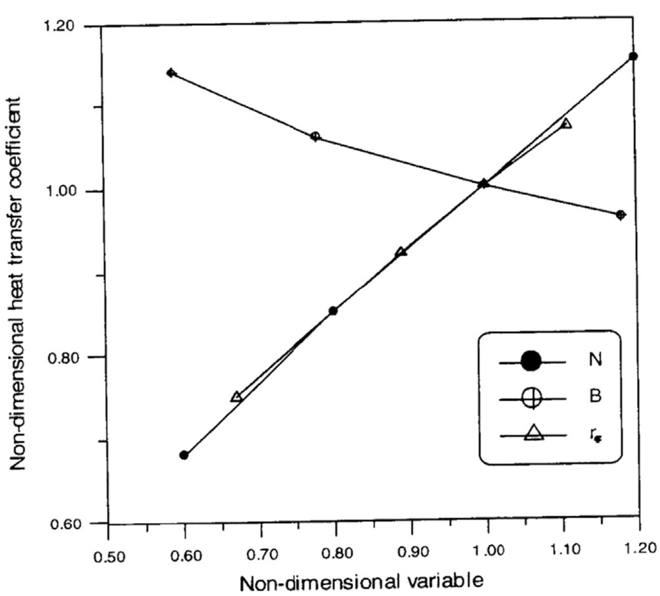

Fig. 10. Effect of non-dimensional variables on heat transfer coefficient.

Dividing the values of variables over their values at the design point produces non-dimensional variables which when plotted versus their performance counterparts, namely Q and h_c, result in Figs. 9 and 10. Fig. 9 shows the relative importance of N and r_c on changing Q at off-design, namely at part load and overload. It similarly shows the relative effect of ϕ and B but in the opposite direction. Fig. 10 shows similar trends but with heat transfer coefficient.

3.4. Gaseous pollutants

3.4.1. Modern and appropriate technologies for the reduction of gaseous pollutants and their effects on the environment [84]

Harmful effects on environment such as global warming and climate change may result from the gases emanating from fossil fuel combustion. Most countries use fossil fuels exclusively.

Therefore, new technologies which could accommodate the demand for cleaner effluents, such as combined cycles, fluidized bed combustion, magneto-hydrodynamics, fuel cells, nuclear power, natural gas, renewable energy and energy conservation have been considered.

3.4.1.1. Transportation potential for saving fuel and the environment. In general, one-third of the oil used in the world is used for transportation, where most of it is consumed by passenger cars and light trucks.

The overall fuel efficiency of the vehicles has increased considerably over the years due to improvements primarily in aerodynamics, materials, and electronic controls. Saving fuel is not limited to good driving habits. It also involves purchasing the right car, using it responsibly, and maintaining it properly. Driving only when necessary is the best way to save fuel, money, and the environment too.

Finally, regular maintenance improves performance, increases gas mileage, lowers repair costs, and extends engine life and reduces air pollution [85].

3.4.1.2. Fuel cells. Existing plants have been required to cut emissions; moreover, there has been a greater emphasis on adopting efficient systems in order to reduce the energy losses. Among high efficiency technologies, fuel cells appear to be the most promising for their high efficiency and their very low environmental impact. Fuel cells are able to convert the fuel chemical energy into electricity, heat and water by an electrochemical reaction called reverse electrolysis [86]. Thus,

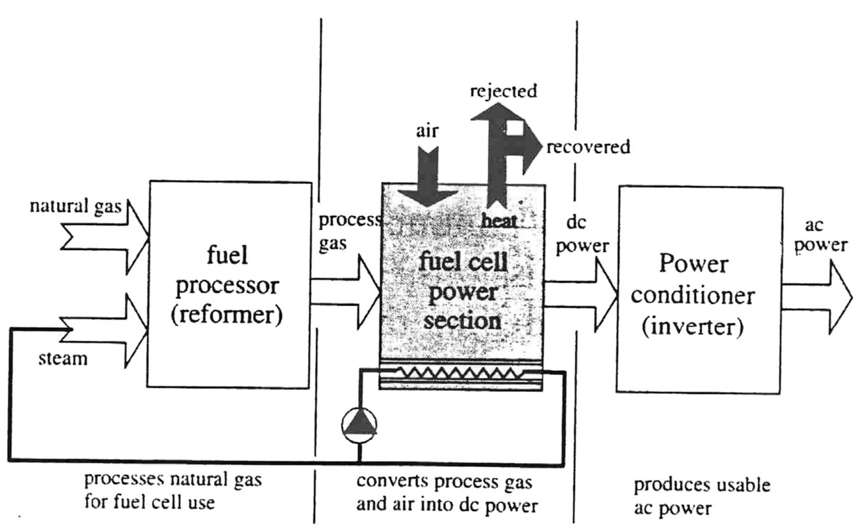

Fig. 11. Schematic drawing of a fuel cell.

fuel cells should allow one to extract much more power from the same amount of fuel, operating without combustion [87].

Accordingly, in order to alleviate the combined threats of climate change, urban air pollution, and quick depletion of crude oil caused by petroleum-based internal combustion engine (ICE) vehicles, it is urgent to develop alternative fuel vehicles that could substantially cut the oil dependence and reduce the carbon footprint of the transportation sector [88,89]

The direct current produced in the fuel cell stack is fed into an inverter system, converting it into alternating current. The whole process is also accompanied by a considerable generation of heat (Fig. 11).

The inconvenience associated with the hydrogen storage and distribution is sometimes overcome by feeding the cells with alcohol fuels and hydrocarbon such as methane, usually directly available from the urban network. Thus, at the same time, a reformer and a desulfurization unit are needed respectively to turn the natural gas into hydrogen and to eliminate the sulfur compounds.

In fuel cells the lack of combustion, a fundamental process in thermal engines, produces substantial environmental benefits by strongly reducing greenhouse gas emissions (CO_2, NO_x, CO_2, etc.). The presence of SO_x is negligible, since the fuel is desulfurized before entering the cell.

There are now a number of factors that are providing the stimulus for fuel cells to play a role in future energy supply and transportation including Zero-Emission Vehicle (ZEV) which has been a major driving force for the development of fuel cell vehicles. Japan's Ministry of Economy, Trade and Industry (METI) has also launched an initiative to encourage the wider use of fuel cell vehicles.

In spite of these future prospects, fossil fuels are likely to remain the primary source of energy for many years. Oil is essential in the transport sector while natural gas will become a more dominant fuel in power generation.

3.4.1.3. Electric vehicles (EV). Electric vehicles have gained tremendous attention from the past decade as one of the promising greenhouse gases (GHG) solution. In the late 20th century, the world crisis had brought up the interest in automobile field due to the continuous rising of global warming consciousness. Transportation sector has been one of the top contributors in the GHG emission globally. The conventional vehicle which operates through ICE from fossil fuels (gasoline or diesel) emits gases such as CO_2, HC, CO, NO_x, water, etc. [90,91].

The EV is one of the solutions to decrease the global GHG emission. By using electricity empowered cars, we are not providing cleaner and quieter ambiance but are also reducing the operating cost drastically compared with gas powered cars. EV spends 2 cents/mile whereas ICE vehicle spends roughly 12 cents [92,93].

There is the “plug-in” electric car. This vehicle is hybrid but runs only on its electric motor. After the battery's charge drops below a certain level, a small gasoline engine must come on to recharge the batteries during travel. The volt's range can be over 300 miles before it must stop to fill up the tank or plug in to recharge (about 4 h for a 240-V outlet) [94]. Moreover, the vehicle and maintenance costs should be added.

3.4.1.4. Biofuels. The increasing energy demand, surging oil prices, depleting oil reserves and environmental pollution problems associated with the use of fossil fuels have sparked renewed interest to find out clean alternative fuels. Alcohols such as methanol, ethanol and butanol are competitive alternative fuels due to their liquid nature, high oxygen contents, high octane number and their production from renewable biomass [95].

Biodiesel, as an alternative fuel for ICE, is defined as a mixture of mono-alkyl esters of long chain fatty acids (FAME) derived from a renewable lipid feedstock, such as vegetable oil or animal fat [96].

Vegetable oils are being used as alternative fuel for a long time. Depending on environmental condition, the sources of biodiesel vary from one country to another like soybean in North America, sunflower and rapeseed for Europe, palm for Southeast Asia, and coconut for tropic and subtropic areas [97]. However, crude vegetable oils are inferior as fuel in terms of viscosity, heating value, freezing point etc. Different chemical treatment like transesterification can improve the fuel properties. The transesterified vegetable oils are widely being used at present.

Parallel to its role in the battle against the climate change, the use of biofuels also contributes to supply security or reduction of the external energy dependence [98], reduces the consumption of petrol and diesel in addition to providing an alternative outlet for farm production and aids in the development of rural areas [99,100]. One of the most advantageous branches in the biofuel sector is seen to be the production of straight vegetable oil (SVO) for direct use as fuel in diesel engines. There has been renewed interest in this activity for stationary applications in the fields of agriculture, power generation and industry. These sectors are major consumers of fuel oils: high (diesel) or medium distillates and heavy fuel oils, thus contributing toward reduction of cost of fossil fuel imports [101].

However, in general deriving biofuels from plantations is necessarily disadvantageous to human feeding and nutrition.

3.5. Engine control

3.5.1. Role of neuro-fuzzy modeling as a greening technique, in improving the performance of vehicular spark ignition engine [102]

The main goal of this paper was to develop a neuro-fuzzy model for fuel injection time in order to design a neuro-fuzzy controller for improving the performance of the spark ignition engine. In this work, experiments were carried out on a four-cylinder, 1.8 L displacement volume, Mitsubishi Engine using a PID controller. Experiments covered a road-load test conditions, from full-load high speed to low-load low speed conditions. This loading procedure was achieved by coupling the engine to a hydraulic dynamometer to get the readings of torque and speed. Engine measurements were taken using a scan tool and exhaust gas analyzer.

The obtained results showed that the developed neuro-fuzzy model is capable of predicting the fuel injection time with a mean squared error less than 0.0072. Furthermore, the power produced by the neuro-fuzzy controller has higher values of about 15–30 % than the power produced by the PID controller used in the basic engine. The BSFC is reduced by about 2–5% compared to the PID controller [103–105].

If the requirements are known, the engine test can be restricted to the conditions of interest with a considerable saving in time and effort. This experiment covers such a situation, the road-load requirements for automobiles. Combustion engines probably encounter their greatest variety of possible operating conditions when used to power automobiles [106–108]. The automobile engine is required to operate over a 10:1 speed range, generally at light loads, but frequently utilizing its reverse power over this speed range for accelerating, ascending a grade, or pulling a trailer. All these requirements must be met quietly, smoothly and with reasonable specific fuel consumption [109–111].

In modern spark ignition engines, the amount of fuel injected is controlled by the conventional PID controller that controls the pulse width (PW) applied to the fuel injector [112]. The control map in the conventional PID is represented by three-dimensional

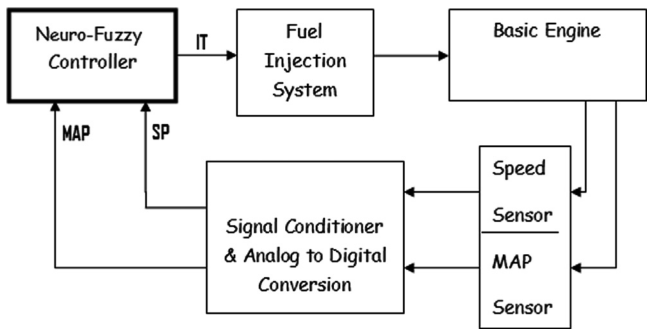

Fig. 12. Simplified block diagram for implementation of proposed neuro-fuzzy controller.

nonlinear relationship between the IT (controller output) and the controller inputs: engine speed (N) and manifold air pressure (MAP) [113]. However, due to the non-linear nature of this control with the spark ignition engine and the ageing effects of its parts, this controller does not provide good accuracy at each operating point of the engine. Thus, a more accurate digital control system would give better results in terms of performance and pollution [114]. This is why a fuzzy controller for regulation of fuel injection was developed [115]. However, such model has two main limitations. First, it needs experts for formulation of fuzzy rules and the model accuracy is limited by the number of these rules. Second, it lacks the capability for self-tuning of the model parameters. In contrast, the neuro-fuzzy controller which is an integration of both neural and fuzzy approaches enables the designer to build more intelligent controller because it incorporates the advantages of both neural networks (robustness, self-learning and tuning) and fuzzy logic (ability to deal with vague data and nonlinear processes) [116–118].

3.5.1.1. Neuro-fuzzy model of injection time. The main objective of the proposed neuro-fuzzy model is to design an intelligent controller for regulating the fuel injection. It estimates the optimal value of injection time using two measured input signals: the engine speed (SP) and manifold absolute air pressure (MAP). As shown in Fig. 12, the engine speed and MAP are used as input to the neuro-fuzzy controller (NFC) which determines the injection time and use it in the fuel injection system.

In conclusion this paper introduces an adaptive neuro-fuzzy model that can be used to design an intelligent controller for the regulation of fuel injected in the spark ignition engine.

4. Conclusions

1 The effects of progressive combustion, valve timing, heat transfer, and friction on performance were obtained for both S.I.E. and CIE over a wide range of operating loads and speeds.
2 Performances with gasoline and diesel fuels were compared over a range of operating speeds for the same engine.
3 Compact S.I. engines showed improvements of 20% in $\eta_{b,th}$ and 10% in power, relative to the conventional one.
4 Using charge stratification increases $\eta_{b,th}$ by 50% relative to conventional engine.
5 Heat transfer affects the exhaust temperature and consequently the power and pressure ratio of the turbocharger.
6 Gas-side heat transfer can only be defined empirically, due to the rapidly changing conditions, within engine cylinders.
7 Unique P–V and P–r_c cycle plots were produced for four alternative fuels including alcohols, gaseous fuels and hydrogen.
8 The use of modern and appropriate technologies such as energy efficiency, adopting alternative fuels, and fuel cells, electric vehicles and biofuels are necessary for the reduction of gaseous pollutants.
9 Using the neuro-fuzzy-based control system in comparison with the conventional PID controller, currently used in most engines, the power improved by about 15 % while the BSFC reduced by about 2–5 %, thus relieving the environment from thousands of tons of CO_2 and other gaseous pollutants.

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